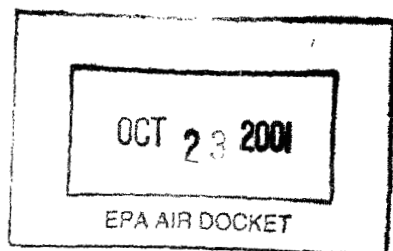# Economic Analysis of U.S. MTBE Production Under an MTBE Ban
DRAFT REPORT

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MTBE MERCHANT PLANTS

SUMMARY

The purpose of this study is to determine what may happen to merchant MTBE plants if and when MTBE is banned as gasoline blendstock.

As discussed below, 107,000 Bbls/day (approximately 42%) of MTBE producing capacity is from refinery-associated plants. These plants will most likely be converted to either isooctane or its feedstocks will be converted to alkylate. The nearly 30% or 75,000 Bbls/day of MTBE produced via butane dehydrogenation is certainly the most economically vulnerable of all MTBE plants. This is because of the high cost of this process compared to the other routes. Most of this report is destined to discussing the economics of MTBE via butane dehydrogenation as well as the economics of converting merchant MTBE plants to alkylate production. Some 20% of MTBE production (50,000 Bbls/day) originates from TBA (tertiary-butyl alcohol), which is a by-product from the chemical manufacture of propylene oxide (PO). The alternative for these producers is basically to sell TBA as a gasoline oxygenated blendstock. The 50,000 Bbls/day of MTBE are equivalent to approximately 40,000 Bbls/day of TBA.

The balance (23,000 Bbls/day) of the MTBE plants use C4 raffinate (from butadiene production) as feedstock. These plants would most likely shutdown and the feedstock would be used by refiners to produce alkylate.

Historically, the economics of producing MTBE via dehydrogenation have been far more favorable than the economics of producing alkylate. MTBE's much higher octane leads to higher product value and the historically low price of methanol on the U.S. Gulf Coast provides lower overall feedstock cost. The result of our analysis is that alkylate must be sold at prices considerably higher than its historical octane blending value to allow a dehydrogenation plant operator to convert an MTBE plant into alkylate production.

In the future, however, there is little doubt that the value of alkylate relative to other gasoline blending components will exceed the historical price relationships. Refiners and blenders may be unwilling to execute long term contracts with dehydrogenation plant operators to buy alkylate at price premiums that are significantly higher than historically based octane values have so far supported. Without such contracts and premium prices, MTBE plant operators may be less willing to invest in a new operation. On the other hand, alkylate may well command a substantial premium in view of the "green value", which a clean gasoline blending component will require if and when MTBE is banned nationally. The reason for this potential premium is that the complete banning of MTBE will remove approximately 150,000 Bbls/day of valuable, clean and high-octane gasoline blending component from the supply scenario.

MTBE SUPPLY BACKGROUND

The elimination of MTBE from the motor gasoline pool naturally may render a good deal of expensive manufacturing hardware essentially useless (beyond scrap value) unless other economically fruitful applications can be found. U.S. companies currently have capacity to produce around 255,000 Bbls/day of MTBE. For perspective, this capacity equates to about 10% of U.S reformulated gasoline (RFG) production in 1999 (Department of Energy statistics).

The following table shows the breakdown of U.S. MTBE production according to the type of feedstocks and type of process:

Type of Plant	Primary Feedstock	Capacity, Bbls/Day
Refinery Associated	FCCU butylenes	107,000
Dehydrogenation	Normal Butane	75,000
Petrochemical	TBA	50,000
Petrochemical	Butylenes from Ethylene	23,000
Total U.S. Capacity		**255,000**

Approximately 42% (107,000 Bbls/day) of this MTBE capacity is represented by refinery-based units, designed to utilize "in-house" by-product supplies of feedstock isobutylene from their associated fluid catalytic cracking (FCCU) facilities that are operated to convert heavy oils into light transportation fuels. Co-feedstock methanol typically is purchased externally. Essentially all of the MTBE produced within refineries is "captive" material for use within the company's own gasoline blending system.

Approximately 73,000 Bbls/day of MTBE capacity (around 29%) lies in the petrochemical sector. The major sources here are those companies making propylene oxide (PO) and utilizing associated tertiary-butyl alcohol (TBA, the by-product of PO manufacture by the latest technology) for conversion into isobutylene. A smaller source in the petrochemical sector is the ethylene industry, which also has some by-product isobutylene available from steam cracker C4 raffinates (*i.e.*, butadiene-depleted) for further processing into MTBE.

The remaining 29% or so (approximately 75,000 Bbls/day) of U.S. MTBE production is derived from plants using butane dehydrogenation and isomerization technologies to make the required isobutylene feedstock. Again, co-feedstock methanol typically is brought in from external sources. Such plants not are directly integrated with petroleum refining operations and are referred to as Merchant Plants. Given that the dehydrogenation route yields the most costly MTBE product and the producers are largely independent of the refining and petrochemical industries in other aspects, we can state with confidence that these producers are the "swing" (or incremental) sources of MTBE supplies that balance the market.

Almost all FCC-based MTBE plants are "captive", with most (if not all) of the production consumed internally. Almost all PO/TBA-based and dehydrogenation-based MTBE, on the other hand, is "merchant market" material sold either on a term contract basis or on a spot basis to gasoline manufacturers/blenders. Although some refiners do own and operate these plants (Valero and Lyondell as examples), we know of no such units that are not selling MTBE to other companies as well.

MTBE from ethylene plant raffinates falls somewhere in the middle of the captive-merchant spectrum. In some instances, an integrated refining/petrochemical company simply combines the C4 stream from the ethylene operation with FCC butylenes for further processing internally. In other situations, companies gather and process various C4 streams from both refineries and ethylene units, with the MTBE output used internally and/or routed to merchant sales.

"MTBE BAN" OPTIONS

Data Sources

Pace has utilized a number of sources in the development of the analyses described herein. Specifically, we have addressed information presented in *"Petroleum Refinery Process Economics"* (R. E. Maples), *"Petroleum Refining – Technology and Economics"* (J. H. Gary and G. E. Handwerk), *"Handbook of Petroleum Refining Processes"* (R. A. Meyers), the *"Oil and Gas Journal"*, *"Hydrocarbon Processing"*, and other published sources. Other information from technology vendors and operating companies regarding current technological advances has been utilized to lesser degree to help shape our analyses. None of this information is in any sense proprietary on the parts of the providers and thus, on the part of Pace. Pace's judgements regarding the validity of any particular pieces of information, however, naturally come into play as a part of our contracted consulting function.

Scenarios

California, of course, has prohibited the practice of blending MTBE into gasoline because of its detected presence in drinking water supplies via leaking underground storage tanks and (in some cases) poor handling practices. Other parts of the country (*e.g.*, several East Coast states) have expressed similar concerns regarding MTBE's potential for polluting groundwater. In the event that the rest of the country follows California's lead entirely or in substantial fashion, the implications for MTBE producers in this country potentially are enormous.

The problem is that U.S. dispositions for MTBE and its feedstocks outside the domestic gasoline pool are very limited in an economic sense. The impact on suppliers of co-feedstock methanol would be tremendous, of course, since MTBE manufacture represents roughly one half of U.S. methanol demand. The impact on domestic gasoline

manufacturing capabilities also would be quite substantial if oxygenates were to remain a mandated part of RFG formulations and ethanol were to be the only viable oxygenate available, absent ethers. For purposes of this investigation, however, we will stick to the subjects of butylenes (particularly isobutylene) and MTBE itself in terms of exploring "MTBE Ban" options.

Simply selling isobutylene or mixed butylenes as such into the petrochemical markets does not appear to be an economically viable option. Petrochemical demand for such materials is small compared to the amount currently being used to make gasoline blendstocks, so attempting to force these volumes into a market already well satisfied by established sources is a losing proposition on its face. These prospects are particularly dim for makers of on-purpose butylenes via dehydrogenation (*i.e.*, merchant MTBE plants) because their C4's would be much the highest cost products on the market.

Similarly, continuing to make MTBE full-bore and attempting to export the product in the event of a total U.S. MTBE ban also appears a very limited option. Domestic producers are faced with very formidable offshore competition in the form of companies with low feedstock costs. There are three major producers outside the United States: Saudi Arabia, Canada, and Venezuela. Producers in the Caribbean (e.g., Venezuela) also experience a small freight advantage versus most others, given the shorter hauls involved.

The details of feedstock pricing vary by location and terms of the contracts, but a quick analysis of a few pricing scenarios does provide perspective. The average price of normal butane at Mont Belvieu (the Gulf Coast reference point) over the past seven years (1994-2000) is 43¢/gal. Butane priced at the equivalent of $1.00/MMBTU, as an example for a hydrocarbon-rich exporting country, is about 10¢gal, yielding the offshore producer an MTBE cost advantage of 33¢/gal.

All non-U.S. producers do not necessarily enjoy such a large feedstock cost differential, of course. This rough calculation does, however, point out the prospective plight of a merchant dehydrogenation-based producer on the U.S. Gulf Coast. These operators almost assuredly will continue to make as much MTBE as they can sell domestically at reasonable capacity utilization rates. However, if remaining U.S. MTBE use is reduced very substantially or is banned outright, it would be extremely difficult for these producers to survive based on export sales.

Given that selling butylenes or exporting MTBE are not likely to be particularly viable routes for most current MTBE producers, their remaining options basically devolve as follows:

1. Discontinue isobutylene production.
2. Convert MTBE capacity to isooctane production.
3. Convert MTBE capacity to alkylate production.

Option"1" does not apply to refiners, of course. Their isobutylenes are part of the mixed C4's stream from cat cracking operations, and therefore cannot simply be turned off.

Before the advent of MTBE, these streams were almost universally routed to alkylation units, which combine the olefins with isobutane to make high-octane gasoline blendstocks. The later MTBE units basically were placed in line ahead of the alkylation units, where they selectively reacted the isobutylene to make MTBE, and left the remaining olefins to pass through to alkylation.

If MTBE is banned, some refiners possibly could simply shut down the etherification step and resume the time-tested practice of alkylating all their cat cracker C4's. Alkylate is not only high in octane, but it also has low vapor pressure, no olefins, and no sulfur. It therefore is a favored component for RFG blending.

U.S. refiners' original alkylation reactors typically were sized to handle all of this C4 material. Increases in cat cracker throughputs and the resultant light ends volumes, however, seem to have absorbed the alkylation capacity initially made available by conversion of part of the feed to MTBE for the majority of refiners. Increased sales of propylene (also an alkylation unit feed) into the petrochemical markets would be unlikely to relieve the capacity pressure.

Accordingly, we expect that the closure of refinery-based MTBE units in many cases would require incremental expansions of alkylation capacity. Another route to absorbing the "new" C4's freed by MTBE closures would be conversion to isooctene and/or isooctane production with relatively minor capital expense. Olefinic isooctene from the relative small volumes of isobutylene produced by cat crackers probably could be accommodated without great difficulty by many of the large refineries that are in place on the U.S. Gulf Coast.

Option "1" also seems unlikely for the PO/TBA-based MTBE producers. These companies are driven primarily to make PO, with TBA relegated to the status of by-product. Companies such as ARCO Chemical attempted in the past couple of decades to develop markets for TBA as a gasoline blendstock (high octane oxygenate) without notable success. The subsequent route chosen has been to dehydrate the TBA to high-purity isobutylene, which subsequently is etherified with methanol to MTBE with good yields.

These companies will continue making PO to meet their market demands, and thus will continue to have TBA on hand. Given the very small market for TBA itself, continued conversion to isobutylene and further processing into gasoline blendstocks appears as one alternative. Conversion of isobutylene into alkylate certainly could be one such route. Another alternative is simply to try to sell TBA as a gasoline blending component.

On the other hand, these producers also could choose to polymerize ("dimerize") the isobutylene directly (without consuming isobutane) to make isooctene and/or isooctane. These products also are good gasoline components with even higher octane ratings than alkylate, and the dimerization reactor system is less costly in capital terms than a similarly sized alkylation plant. Accordingly, Pace anticipates that some of the PO/TBA-based MTBE manufacturers will switch to isooctene/isooctane production if the MTBE

market is closed out. ARCO already has received a patent for their version of this process.

Turning to dehydrogenation-based MTBE producers, all three of the options noted above (shutdown, isooctene/isooctane conversion, alkylation conversion) are in play. These companies have made major capital investments over the last several years, and would certainly hope to maintain their currently positive cash flows so as to maximize returns on these investments over the useful lifetimes of their facilities. Accordingly, it appears almost a given that essentially all such companies will continue to produce MTBE to the fullest extent the markets will support in terms of economically viable operating rates and product netback values.

Once cash flows turn negative, however, many in the dehydro-based MTBE segment could simply opt to exit the business rather than expend further capital to make new products at their sites. These closures could take course over the period of a U.S. MTBE phase-down to zero, or to a level that would squeeze out the higher-cost producers. If the ultimate MTBE target is zero for domestic use, closures of all U.S. dehydro-based MTBE plants may certainly be the outcome.

For those in this category considering their choices for staying in business while making alternative gasoline blending products, isooctane and C4 alkylate are the natural routes of interest. Dehydrogenation plays a role in each process scheme, so this particular set of the equipment is the part not wasted through re-deployment of the business. The general physical results of converting existing facilities to these alternative applications are illustrated by the accompanying Figures 1, 2, and 3, and quantified in Table 1.

Figure 1 establishes a reasonable representation of butane dehydrogenation-based MTBE facilities in place on the U.S. Gulf Coast today. Mixed butanes from field sources are the first of the raw materials (methanol being the second). The mixed butanes are fed to a de-isobutanizer (DIB) tower that separates via fractionation the contained isobutane from the accompanying normal-butane (n-butane), and also handles recycled butanes from the entire system. The n-butane is delivered to the isomerization (Isom) reactor for conversion into isobutane. The combined isobutane stream (naturally contained feedstock plus isomerizer yield) is fed to the dehydrogenation (Dehydro) reactor section for conversion to isobutylene. Subsequently, the isobutylene is combined with methanol (the second raw material) in the etherification reactor section to yield MTBE.

A typical size for the process plant depicted here is 15,000 Bbls/day of mixed butane feed. Combined with 5,130 Bbls/day of methanol, this C4 input will yield some 15,090 Bbls/day of MTBE (Table 1). Density changes through the chemical processes and loss of some hydrocarbons to the plant fuel system account for the difference between "barrels in" and "barrels out".

The flow scheme for making isooctane (Figure 2) is the same as described above through the dehydro step. In this case, however, rather than reacting the isobutylene product from the dehydro unit with methanol to make MTBE, the isobutylene (C4) molecules are

combined with themselves in the polymerization ("dimerization") reactor to make isooctene (C8) molecules. This reactor system necessarily is new equipment for the most part, because the pre-existing etherification equipment is not entirely convertible to this service in all circumstances.

Isooctene is an olefinic gasoline component, and olefins typically are "bad actors" regarding RFG production. Accordingly, this plan encompasses the hydrogen released via the isobutane dehydrogenation step being utilized for recombination with isooctene to convert it to isooctane ("hydrogenation" in Figure 2). Isooctane is a non-olefinic, high-octane, no-sulfur blendstock that probably would find greater acceptance in most RFG formulations than isooctene.

While the technology involved is adequately proven, one of the economic problems associated with conversion of a dehdyro-based MTBE plant to isooctane production is the yield factor. Making MTBE from C4's and methanol in the base configuration results in virtually a one-to-one correspondence between "barrels in" and "barrels out". This process has the virtue of upgrading both the butane and the methanol feedstocks to "gasoline-plus" product values.

However, the "barrel balance" changes significantly when the etherification step is replaced by the polymerization step to make isooctane. Co-feedstock methanol no longer is in the picture, and we simply are left with the dimerization of C4 olefins to make (ultimately) a C8 paraffin (isooctane). The product isooctane has greater density than the feedstock C4's. Consequently, the original 15,000 Bbls/day of butane raw material yields just 10,368 Bbls/day of isooctane product in this conversion example (Table 1).

This volumetric shrinkage associated with the isooctane route can be acceptable in some cases. Access to transportation facilities (limited or unlimited), costs of feedstocks, and the product consumers' needs/values for isooctane are among the many variables driving these conclusions. The relatively low incremental capital cost associated with the polymerization reactor system is another. A couple of dehydro-based MTBE producers might well choose to convert to isooctane manufacture as a result.

Nonetheless, we expect that the majority of dehydro plants faced with the close-or-convert decision would look more favorably on alkylation as the conversion option, versus isooctane. The reasoning here, again, is volumetric. Butylene alkylate has lower octane content than isooctane. However, an existing butane dehydrogenation plant of the same size discussed above potentially can yield roughly twice as much as alkylate as isooctane, a factor that well outweighs the quality deficit in terms of stand-alone economics.

The "alky conversion" flow scheme for the example dehydro-based plant is graphically presented in Figure 3. The key difference here is that while the isooctane system reacts isobutylene with isobutylene, the alkylation system reacts primarily normal butylenes with isobutane. Thus, the dehydrogenation reaction systems and the isomerization reaction systems can be operated essentially in parallel, thereby almost doubling the

volumes of hydrocarbons that can be handled through the "front end" of the process. The "back end" etherification section, of course, is again junked in this case, and replaced by an acid-catalyzed alkylation reaction section.

As shown in Figure 3, a mixed butanes feed would be routed to the DIB fractionator and the n-butane portion taken to the associated isomerization system to maximize isobutane availability. Meanwhile, a separate purchased C4 stream would be fed to the dehydrogenation section to make butylenes. The two products from these systems (isobutane and mixed butylenes) subsequently would be delivered to the new alkylation reactor (replacing the existing etherification system), thereby yielding C4 alkylate (of which isooctane itself is a major component).

The ability to maximize utilization of existing dehydrogenation-based MTBE facilities is quantified in Table 1. The assumed typically sized plant can make 15,090 Bbls/day of MTBE, 10,368 Bbls/day of isooctane (with new capital investment), and 22,018 Bbls/day of alkylate (with greater new capital investment). Given the better volumetric yield, it is likely that a considerable portion of dehydro-based MTBE producers would prefer alkylation to isooctane as a conversion option in the event of a large-scale MTBE ban.

Both conversion routes are defensive to a large degree versus the "shutdown" option, of course. The main factors of concern in the "conversion" cases are the capital expenditures needed for the new reaction and product recovery systems, and the propensities within the gasoline-manufacturing sector to return values for the new products that satisfy the dehydro-based producers' cost needs. Because alkylation appears to have the advantage versus isooctane for most U.S. producers, Pace's subsequent comments will focus initially on the economics of alkylation via dehydrogenation of butanes.

ALKYLATION CONVERSION ECONOMICS

The conventional means for assessing a gasoline blendstocks values, absent in-depth refinery analyses that encompass environmental regulations as a whole, is simply to consider the blendstock's blending vapor pressure and blending octane versus finished gasoline specifications. Reid Vapor Pressure ("RVP") and road octane rating ("R+M/2") are the factors involved here. For purposes of this examination, we have assumed that the RVP specification is 8 psi (Gulf Coast summertime), and that the saleable octane ratings are 93 R+M/2 for premium gasoline and 87 R+M/2 for regular gasoline.

We further have assumed the qualities of the alkylate from the C4-based process to be 2.0 RVP and 95 R+M/2 octane. A number of quality measures in these regards are among the published data, depending on the processing technologies involved. Pace has chosen for our "bases case" evaluations the most favorable characteristics reported for a particular system (lowest RVP, highest octane). Other, less favorable, characteristics naturally would tend to depress the economic results versus those reported herein.

The RVP evaluation takes into account the quality of the blendstock and the quality of n-butane versus the required RVP standard for finished gasoline. Normal butane addition (or inclusion) is the standard means by which refiners adjust their gasoline pool volatility to meet specifications. Butanes are made throughout the refining process, and removed via fractionation ("debutanizer") systems to insure that the associated gasoline blendstock streams will not lead to a breech of allowable standards. Subsequently, butane is re-introduced to the gasoline pool to bring the pool-average RVP quality up to maximum specification levels. Gasoline blendstock debutanization followed by butane re-introduction is a fundamental quality control technique in refineries.

This re-introduction of normal butane to the gasoline pool serves a number of purposes. First, it enhances gasoline volume production. Second, it enhances gasoline octane rating because normal butane is a high-octane component. Third, it basically upgrades what is essentially a relatively low-valued hydrocarbon outside the gasoline pool (heating butane) to gasoline values. Blending butane into gasoline is one of the things refiners very much prefer to do within the extent allowed by specifications.

The RVP blending relationships utilized by Pace in this study are represented below:

RVP BLENDING ADJUSTMENT

	Volume	RVP	R+M/2
Alkylate	1.0000	2.0	95.00
N-Butane	0.1176	59.0	91.00
Alky Mix	1.1176	8.0	94.58

As shown, the addition of an incremental gallon of C4 alkylate to the gasoline pool allows for the inclusion of an incremental 0.1176 gallon of n-butane within a summertime gasoline specification of 8.0 psi RVP. The resultant RVP-adjusted mix has an octane rating of 94.58 R+M/2, well in excess of the 93 R+M/2 rating for premium gasoline predominant on the Gulf Coast market. Accordingly, this mix is afforded a blending value that is greater than the premium gasoline price itself.

The spot price differential between premium and regular gasoline grades reflects the value that the market places on incremental octane content. For example, the U.S. Gulf Coast spot price spread between 93-octane premium and 87-octane regular (both conventional unleaded fuels) averaged 3.6¢/gal in 2000. This spread for six octane numbers equates to a value 0.6¢/octane-gal. Applying this market-related octane value to the implied value of the RVP-adjusted alkylate mix is accomplished via the following calculations:

ALKYLATE BLENDING VALUE CALCULATION – 2000 PRICES

	Gallons	R+M/2	Octane-Gals	Price ¢/Gal	Value ¢/Gal
Alkylate	1.0000	95.000	95.000		96.569
N-Butane	0.1176	91.000	10.702	67.00	7.879
Prem Gaso	(1.1176)	93.000	(103.937)	92.51	(103.389)
Octane-Gallons			(1.765)	0.60	(1.059)
Balances	-0-		-0-		-0-

From the above, the RVP-adjusted alkylate mix (1.1176 gallons) yields 105.702 octane-gallons. The same volume of premium gasoline would require only 103.937 octane-gallons, so the mix contains a "surplus" of 1.765 octane-gallons that benefits the value calculation. Assigning the base 1.1176 gallons the spot price of premium gasoline and crediting the surplus octane content at the incremental market value thus yields an imputed value of 96.57¢/gal for alkylate. This alkylate blend value for 2000 exceeds the spot price of premium gasoline itself by some 4.1¢/gal.

This result is typical for alkylate blending evaluations. Based on the conventional measures of RVP and R+M/2 octane, the blend value of C4 alkylate has ranged roughly between 3¢/gal and 4¢/gal above spot premium gasoline prices on the Gulf Coast over the past seven years. This very stable relationship is illustrated by the graphical bottom line in Figure 4.

We must note here that Pace has assumed virtually the "best case" for alkylate blend values in the calculations described above. Publicly available data include a fairly wide spectrum of C4 alkylate vapor pressures and octane ratings, depending on the technology employed. Our assumptions of 2.0 RVP and 95.0 R+M/2 are toward the top of the list regarding quality.

Other sources would peg 4.5 RVP and 94.0 R+M/2 as the operative figures. If we assume these latter qualities for the alkylate, the blending value for year 2000 is lowered to 94.78¢/gal. This result is roughly 2¢/gal below the figure derived above for the "best case", and is only 2.3¢/gal above the USGC spot price of premium gasoline. This comparison demonstrates the degree of sensitivity of apparent C4 alkylkate blending values to product qualities that might be recognized in the markets. A value difference of 1¢-2¢/gal due to quality could be rather substantial in terms of the economic outlooks for both merchant alkylate producers and the prospective consumers of their product.

Alkylate Price Implications

Table 2 presents the key economic factors for a butane dehydrogenation-based alkylation plant operating on the U.S. Gulf Coast, "backcast" over the past seven years. As shown, alkylate sold at its blending values calculated from RVP and octane qualities would have generated positive annual cash flows in only one year of the seven, 1994. Net cash losses

amounting to as much as 6¢/gal would have been recorded in the ensuing years from 1995 through 2000. These estimated cash losses would have been relative only to out-of-pocket expenses for feedstocks, utilities, labor, maintenance, and so forth, and not including "book" expenses such as depreciation or ROI.

Also presented in this table are the annual average plant-gate netback values for alkylate needed to allow the hypothetical dehydrogenation-based alkylation unit operator to achieve cash breakeven economics. The difference between the alkylate blending value and the needed netback price is labeled the "green premium" because alkylate is seen as a key component in the formulation of environmentally-beneficial "green" gasoline (RFG). The associated premium is the amount the gasoline makers would have to be willing to pay above simple blending values to sustain the supply of alkylate on the cash breakeven basis for dehydro-based producers. This green premium naturally is the inverse of the cash margins listed above, and thus has risen from 1¢/gal in 1995 to a bit more than 6¢/gal as of 2000.

Simply achieving cash cost breakeven, of course, would provide no incentive for the butane dehydro-based facilities to stay in business, particularly given the additional capital expenditures required. The dehydrogenation and isomerization facilities would remain in place, but none of the etherification reaction section would be convertible to alkylation service. A new alkylation plant of this size would involve a capital investment of approximately $71.5 million. Achieving a simple before-tax return on this investment (BTROI) of 25% would require an additional cash flow (above cash breakeven) of $17.875 million per year, or nearly 5.6¢/gal of alkylate.

Thus, as also shown in the lower portion of Table 2, the plant netback price of dehydro-based C4 alkylate would have to be almost 12¢/gal above its current simple gasoline blending value to yield a minimal return on the new alkylation unit investment. This so-called "ROI green premium" does not include the costs of transporting the alkylate to the refinery, which would add to the implied premium amount regardless of which party actual bears the cost. If the purchasing refiner were located on the East Coast, the associated pipeline shipping and handling costs likely would be on the order of 3¢-4¢/gal. Whether gasoline producers would be willing or able to pay premiums over blend values of this magnitude for alkylate to replace MTBE is very questionable at this point.

Gasoline Price Implications

Since alkylate is fundamentally an octane-enhancing blendstock, its value naturally responds positively to increases in octane values. As described above, the most straightforward octane value measure used in the market is the price spread, or difference, between premium gasoline and regular gasoline. The spot price spread between 93 R+M/2 conventional unleaded premium and 87 R+M/2 conventional unleaded regular on the U.S. Gulf Coast has ranged between 5.4¢/gal and 3.6¢/gal over the last seven years, as illustrated by the lower solid line on Figure 5.

These spreads for six octane numbers thus have yielded incremental octane values from 0.9¢/octane-gal to 0.6¢/octane-gal during this time. Again, alkylate blending values utilizing these octane values would have produced net cash losses for dehydogenation-based alkylation plants for every one of the last seven years except 1994, when 93-octane premium was still a relatively new product in trade. These results were presented earlier in Table 2, and are repeated for reference in Table 3. Even more disconcerting for prospective operators of these plants, the price spreads and the associated octane values have been on a downward trend over the years.

We have calculated, using the bases already established, the octane values that would have been needed for dehydro-based alkylation economics to reach certain benchmark levels. For cash breakeven performance, these octane values translate into premium-regular spreads ranging from 4.8¢/gal to 8.3¢/gal from 1994 to 2000, as shown by the dashed line on Figure 5. The data series labeled "Cash Breakeven 'Octane Premium'" on Table 3 provides the amount by which the spread would necessarily have increased versus the actual for each year (as little as 0.7¢/gal to as much as 4.3¢/gal).

Again, cash breakeven represents poor performance in the face of substantial capital outlay. Providing alkylate blend values that would return 25% BTROI would have required premium-regular spreads in the realm of 8.3¢/gal to 11.9¢/gal during the time frame considered (Figure 5 again). Thus, the "ROI Octane Premium" data in Table 3 show that the spreads would have had to be from 2.9¢/gal to 8.3¢/gal above the actual results. The latter figure, most significantly, is the implied octane premium needed for year 2000.

Certainly, barring MTBE from gasoline formulations would remove a substantial volume of octane-gallons from the pool. This situation of tightening octane supply balances would imply upward pressure on incremental octane values, as reflected by widening gasoline grade price spreads. Whether last year's 3.6¢/gal spread could actually have jumped to nearly 12¢/gal in such circumstances is very much a problematic proposition, however.

If other, cheaper new octane supplies could be obtained in volumes sufficient to curtail the increase in grade spreads below the "target" levels, the proposed dehydro-based alkylation would be shut out of the market. Such new supplies could come from domestic PO/TBA-based alkylate or isooctane, domestic refinery-based alkylate utilizing in-house isobutylenes, and a number of foreign sources. Equally likely is that a sharp jump in the premium-regular spreads would produce a negative reaction in premium gasoline demand (assuming it were passed through to consumers at the pump), thus easing the pressure on octane supplies from the consumption side. In any event, the economic prospects for conversion of these dehydro-based plants are a bit grim.

Other Considerations

Adding to the "grimness" outlined above is the possibility that the "green premiums" would not be available for the entire year. The likelihood is that buyers would support

some or all of the premium for only the peak gasoline production period, which is roughly half the year. Very small or non-existent premiums might well prevail for the remaining six months. The economic prospects obviously become much worse in light of this factor. The BTROI expectations at our proposed premiums would fall to 12.5%, for example, or payout periods would double. When prospects are marginal at best, halving them is very nearly a death knell.

One factor that would make dehydogenation-based MTBE producers feel more confidant regarding capital spending to convert to other services would be the ability to secure reasonably long-term contracts from their buyers that would defray some or most (or all?) of the ROI risk. However, given the premiums versus their products' blending values that most such converters would need, it appears entirely unlikely that many merchant-market buyers will be willing to participate on this basis. Short-term and/or spot sales would probably characterize the market. Neither producers nor their lenders would be particularly reassured by this market environment.

ISOOCTANE CONVERSION ECONOMICS

Some current dehydo-based MTBE producers might well opt for conversion to isooctane (reference Figure 2), rather than to alkylation, depending on their particular system needs and local economics. Again, however, isooctane is defensive versus alkylation in the general case because of its much lower product yield (refer again to Table 1). The standard dehydro plant assumed in this study would produce only 10,368 Bbls/day (1,036,800 octane-barrels) of isooctane, versus 22,019 Bbls/day (2,091,805 octane-barrels) of alklate. We believe that this situation would push most operators in the direction of alkylation when considering conversion options. Nonetheless, this conclusion necessitates at least a quick examination of isooctane economics to establish the bases.

Isooctane has a better octane rating (100 R+M/2) than C4 alkylate (95 R+M/2 in our calculations), and essentially the same blending vapor pressure. As a result, the calculations presented previously in the case of alkylate yield somewhat higher blend values for isooctane. The difference between isooctane blend values and premium gasoline prices, as illustrated by the lower solid line in Figure 6, has run roughly between 6¢/gal and 8¢/gal over the last seven years. These value differentials are twice as great as the 3¢/gal to 4¢/gal differentials attributed to alkylate.

The better product values notwithstanding, the lower volume yield does impact isooctane economics very substantially. Table 4 presents Pace's evaluation of dehydrogenation-based isooctane economics on the same basis described earlier in Table 2 for alkylate. Here we find that realizing plant-gate values for the isooctane that are simply equal to its blend values would have produced huge net cash losses, rising from a bit less than 9¢/gal in 1994 to nearly 24¢/gal by 2000. Erasing the net cash losses to produce breakeven results thus would entail buyers paying "Green Premiums" of the same amounts.

The isooctane conversion option does have one attraction, in that the new equipment requirements would be less costly than the new alkylation equipment. The major pieces would be the new polymerization reactor section and a hydrotreater to saturate the olefinic polymerization product (isooctene) to isooctane. Preliminary estimates indicate that this investment would be on the order of $30 million, less than half that for the alkylation conversion.

Even, so this capital burden only adds to the substantial premiums needed to sell isooctane at favorable netback values that provide return on investment. Table 4 shows that the "ROI Green Premiums" versus isooctane blend values would be up by another 5¢/gal or so versus the cash breakeven numbers, amounting to nearly 29¢/gal last year. We had concluded that placing alkylate in the merchant market at premiums of nearly 12¢/gal versus blend values would be a tough sales proposition; placing isooctane at premiums more than twice as great would be even tougher. Thus, if dehydrogenation-based MTBE plants are to convert at all, the isooctane option would seem to be second in line for most.

Operating Mode	MTBE	ISOOCTANE	ALKYLATE
TABLE 1			
ALTERNATIVE DEHYDROGENATION-BASED MTBE PLANT CONFIGURATIONS			
BARRELS PER STREAM DAY			
Feeds			
Mixed Butanes	15,000	15,000	13,733
Normal Butane	0	0	15,000
Methanol	5,130	0	0
Products			
Fuel from Dehydrogenation (FOE*)	2,130	2,169	2,026
Less Hydrogen for Isooctene Saturation	0	(441)	0
Fuel from Isomerization (FOE*)	111	111	102
MTBE	15,090	0	0
Butane Purge	62	0	0
Isooctane	0	10,368	0
Alkylate	0	0	22,019
Feed to Isomerization Unit	13,943	13,943	12,766
Feed to Dehydrogenation Unit	29,870	30,215	29,680
Feed to Deisobutanizer Tower	29,083	29,083	26,626
*Fuel Oil Equivalent Barrels @ 6.3 MMBTU/Barrel			

TABLE 2							
USGC DEHYDROGENATION-BASED C4 ALKYLATION ECONOMICS							
ALKYLATE PRICE/VALUE SENSITIVITY							
				CENTS PER GALLON			
	1994	1995	1996	1997	1998	1999	2000
CAPACITY: 22,019 BPSD (323,679 MGAL/YR) ALKYLATE							
FEEDSTOCKS							
Mixed Butanes	(20.97)	(22.86)	(28.39)	(26.31)	(18.33)	(24.43)	(40.65)
N-Butane	(24.14)	(26.23)	(32.32)	(30.02)	(21.22)	(27.95)	(45.83)
Total Feedstock Costs	(45.11)	(49.09)	(60.71)	(56.33)	(39.55)	(52.37)	(86.47)
VARIABLE OPERATING COSTS							
Fuel	(4.06)	(3.57)	(5.08)	(5.35)	(4.55)	(4.88)	(8.85)
Electricity	(1.30)	(1.33)	(1.37)	(1.39)	(1.36)	(1.44)	(1.50)
Steam	(1.77)	(1.56)	(2.22)	(2.34)	(1.99)	(2.13)	(3.87)
Catalysts & Chemicals	(1.41)	(1.41)	(1.41)	(1.41)	(1.45)	(1.42)	(1.45)
Treated Water	(0.20)	(0.20)	(0.21)	(0.22)	(0.22)	(0.22)	(0.23)
Total Variable Costs	(8.74)	(8.08)	(10.29)	(10.71)	(9.57)	(10.08)	(15.90)
FIXED OPERATING COSTS (1)	(4.62)	(4.74)	(4.83)	(4.95)	(5.00)	(5.05)	(5.05)
TOTAL CASH COSTS	(58.47)	(61.90)	(75.83)	(71.98)	(54.11)	(67.50)	(107.42)
PRODUCTS							
Fuel	2.17	1.91	2.72	2.87	2.44	2.61	4.74
Alkylate (2)	57.13	59.04	67.03	66.25	48.89	59.52	96.56
Total Products	59.30	60.95	69.76	69.12	51.33	62.14	101.31
CASH MARGIN	0.83	(0.96)	(6.07)	(2.87)	(2.79)	(5.37)	(6.11)
ALKYLATE PRICE NEEDED FOR CASH BREAKEVEN	56.30	60.00	73.11	69.12	51.68	64.89	102.68
CASH BREAKEVEN "GREEN PREMIUM" (3)	**(0.83)**	**0.96**	**6.08**	**2.87**	**2.79**	**5.37**	**6.12**
ADD ALKYLATION INVESTMENT							
Needed Margin @ 25% ROI (4)	4.89	5.02	5.14	5.27	5.40	5.42	5.55
ALKYLATE PRICE NEEDED FOR ROI	61.18	65.01	78.25	74.39	57.08	70.31	108.22
"ROI GREEN PREMIUM" (5)	**4.05**	**5.97**	**11.21**	**8.14**	**8.19**	**10.79**	**11.66**
	48.01	51.08	59.93	58.99	41.79	52.37	83.78
	11.29	9.86	9.83	10.13	9.54	9.76	17.52

(1) Includes direct labor, supervisory & administative staff, maintenance, supplies, property taxes and insurance.

(2) Alkylate value derived from vapor pressure and octane blending calculations versus gasoline at 8 RVP and 93 R+M/2.

(3) Alkylate price premium above (below) calculated blending value required to produce cash breakeven economics (zero net cash flow).

(4) Simple before-tax return on alkylation investment only; no further return on pre-existing dehydro and isomerization facilities assumed.

(5) Alkylate price premium above (below) calculated blending value required to produce 25% BTROI on new alkylation equipment investment.

	TABLE 3						
	USGC DEHYDROGENATION-BASED C4 ALKYLATION ECONOMICS						
	PREMIUM-REGULAR PRICE SPREAD SENSITIVITY						
	CENTS PER GALLON						
	1994	1995	1996	1997	1998	1999	2000
CAPACITY: 22,019 BPSD (323,679 MGAL/YR) ALKYLATE							
FEEDSTOCKS							
Mixed Butanes	(20.97)	(22.86)	(28.39)	(26.31)	(18.33)	(24.43)	(40.65)
N-Butane	(24.14)	(26.23)	(32.32)	(30.02)	(21.22)	(27.95)	(45.83)
Total Feedstock Costs	(45.11)	(49.09)	(60.71)	(56.33)	(39.55)	(52.37)	(86.47)
VARIABLE OPERATING COSTS							
Fuel	(4.06)	(3.57)	(5.08)	(5.35)	(4.55)	(4.88)	(8.85)
Electricity	(1.30)	(1.33)	(1.37)	(1.39)	(1.36)	(1.44)	(1.50)
Steam	(1.77)	(1.56)	(2.22)	(2.34)	(1.99)	(2.13)	(3.87)
Catalysts & Chemicals	(1.41)	(1.41)	(1.41)	(1.41)	(1.45)	(1.42)	(1.45)
Treated Water	(0.20)	(0.20)	(0.21)	(0.22)	(0.22)	(0.22)	(0.23)
Total Variable Costs	(8.74)	(8.08)	(10.29)	(10.71)	(9.57)	(10.08)	(15.90)
FIXED OPERATING COSTS (1)	(4.62)	(4.74)	(4.83)	(4.95)	(5.00)	(5.05)	(5.05)
TOTAL CASH COSTS	(58.47)	(61.90)	(75.83)	(71.98)	(54.11)	(67.50)	(107.42)
PRODUCTS							
Fuel	2.17	1.91	2.72	2.87	2.44	2.61	4.74
Alkylate (2)	57.13	59.04	67.03	66.25	48.89	59.52	96.56
Total Products	59.30	60.95	69.76	69.12	51.33	62.14	101.31
CASH MARGIN	0.83	(0.96)	(6.07)	(2.87)	(2.79)	(5.37)	(6.11)
PREM-REG SPREAD, ACTUAL SPOT (3)	5.40	4.57	3.97	3.89	4.13	4.11	3.60
PREM-REG SPREAD NEEDED FOR CASH BREAKEVEN	4.81	5.25	8.28	5.92	6.11	7.91	7.93
CASH BREAKEVEN "OCTANE PREMIUM" (4)	**(0.59)**	**0.68**	**4.31**	**2.03**	**1.98**	**3.80**	**4.33**
ADD ALKYLATION INVESTMENT							
Needed Margin @ 25% ROI (5)	4.89	5.02	5.14	5.27	5.40	5.42	5.55
PRE-REG SPREAD NEEDED FOR ROI	8.27	8.81	11.92	9.66	9.94	11.75	11.86
"ROI OCTANE PREMIUM" (6)	**2.87**	**4.23**	**7.95**	**5.77**	**5.81**	**7.64**	**8.26**

(1) Includes direct labor, supervisory & administative staff, maintenance, supplies, property taxes and insurance.

(2) Alkylate value derived from vapor pressure and octane blending calculations versus gasoline at 8 RVP and 93 R+M/2.

(3) Annual average spot price spread between 93 R+M/2 premium conventional gasoline and 87 R+M/2 regular conventional gasoline.

(4) Additional premium - regular gasoline price spread required to produce cash breakeven economics (zero net cash flow).

(5) Simple before-tax return on alkylation investment only; no further return on pre-existing dehydro and isomerization facilities assumed.

(6) Additional premium-regular gasoline price spread required to produce 25% BTROI on new alkylation equipment investment.

			TABLE 4				
		USGC DEHYDROGENATION-BASED C4 ALKYLATION ECONOMICS					
		ISOOCTANE PRICE/VALUE SENSITIVITY					
		CENTS PER GALLON					
	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
CAPACITY: 10,368 BPSD (152,410 MGAL/YR) ISOOCTANE							
FEEDSTOCKS							
Mixed Butanes	(48.88)	(53.30)	(66.18)	(61.33)	(42.72)	(56.94)	(94.76)
N-Butane	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Feedstock Costs	(48.88)	(53.30)	(66.18)	(61.33)	(42.72)	(56.94)	(94.76)
VARIABLE OPERATING COSTS							
Fuel	(5.75)	(5.05)	(7.20)	(7.58)	(6.45)	(6.91)	(12.55)
Electricity	(2.88)	(2.95)	(3.03)	(3.08)	(3.02)	(3.18)	(3.33)
Steam	(2.96)	(2.60)	(3.70)	(3.90)	(3.31)	(3.55)	(6.45)
Catalysts & Chemicals	(3.76)	(3.76)	(3.76)	(3.76)	(3.85)	(3.77)	(3.86)
Treated Water	(0.46)	(0.48)	(0.49)	(0.50)	(0.51)	(0.52)	(0.53)
Total Variable Costs	(15.81)	(14.84)	(18.18)	(18.82)	(17.14)	(17.93)	(26.71)
FIXED OPERATING COSTS (1)	(9.77)	(10.02)	(10.22)	(10.47)	(10.57)	(10.68)	(10.68)
TOTAL CASH COSTS	(74.46)	(78.17)	(94.58)	(90.62)	(70.44)	(85.55)	(132.14)
PRODUCTS							
Fuel	3.99	3.51	5.00	5.26	4.47	4.80	8.71
Isooctane (2)	61.63	62.85	70.35	69.49	52.33	62.94	99.56
Total Products	65.62	66.35	75.34	74.75	56.81	67.74	108.27
CASH MARGIN	(8.84)	(11.81)	(19.24)	(15.87)	(13.63)	(17.81)	(23.88)
ISOOCTANE PRICE NEEDED FOR CASH BREAKEVEN	70.48	74.67	89.59	85.37	65.96	80.75	123.44
CASH BREAKEVEN "GREEN PREMIUM" (3)	**8.85**	**11.82**	**19.24**	**15.88**	**13.63**	**17.81**	**23.88**
ADD POLYMERIZATION/HYDROTREATING INVESTMENT							
Needed Margin @ 25% ROI (4)	4.34	4.45	4.56	4.68	4.80	4.81	4.92
ISOOCTANE PRICE NEEDED FOR ROI	74.81	79.11	94.15	90.04	70.76	85.56	128.36
"ROI GREEN PREMIUM" (5)	**13.18**	**16.26**	**23.80**	**20.55**	**18.42**	**22.62**	**28.80**

(1) Includes direct labor, supervisory & administative staff, maintenance, supplies, property taxes and insurance.

(2) Isooctane value derived from vapor pressure and octane blending calculations versus gasoline at 8 RVP and 93 R+M/2.

(3) Isooctane price premium above (below) calculated blending value required to produce cash breakeven economics (zero net cash flow).

(4) Simple before-tax return on polymerization/hydrogtreating investment only; no further return on pre-existing dehydro and isomerization facilities assumed.

(5) Isooctane price premium above (below) calculated blending value required to produce 25% BTROI on new polymerization/hydyrotreating equipment investment.
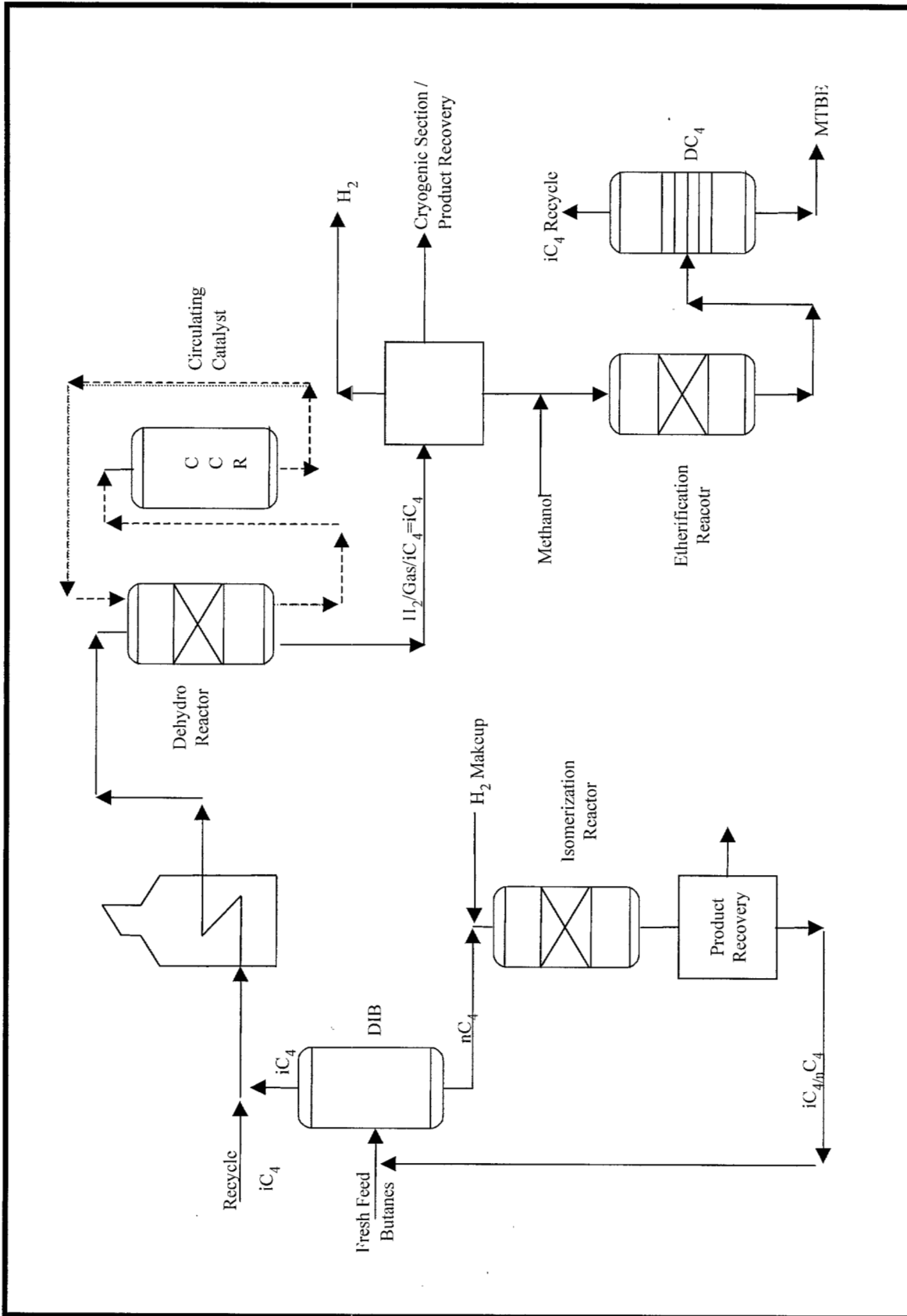
Circulating Catalyst

H_2

Cryogenic Section / Product Recovery

iC$_4$ Recycle

DC$_4$

MTBE

C C R

Dehydro Reactor

H_2/Gas/iC$_4$=iC$_4$

Methanol

Etherification Reacotr

Recycle

iC$_4$

Isomerization Reactor

H_2 Makeup

Product Recovery

DIB

iC$_4$

nC$_4$

Fresh Feed Butanes

iC$_{4/n}$ C$_4$

Figure 1
Dehydrogenation Based MTBE Complex

| DRAWN | KDS | CHECKED | JHJ | APPROVED | | PACE NO. | 61-Y910-00 | DRAWING NO. | 001 | REV. |
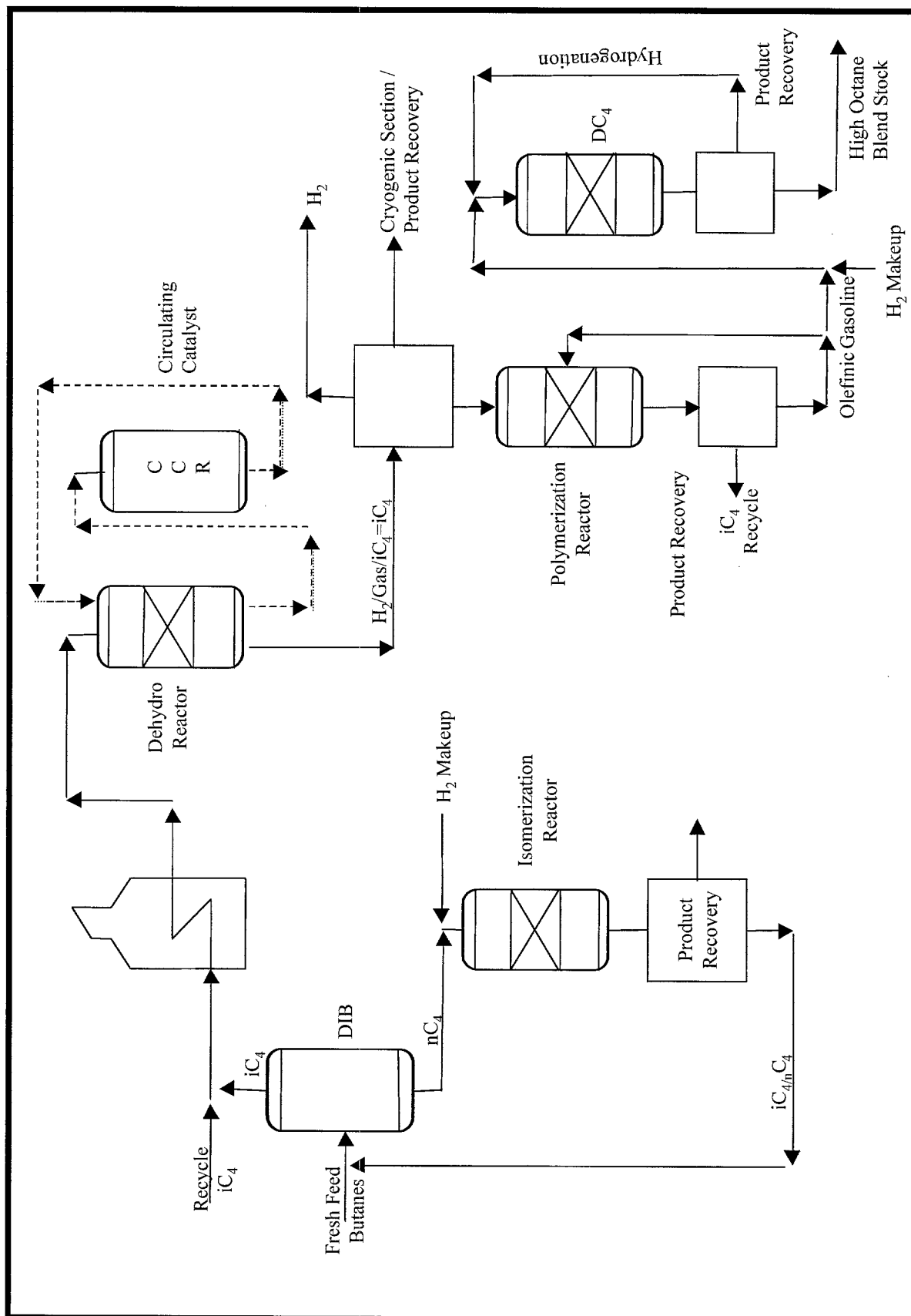
Figure 2
Isooctane Conversion

Figure 3
Alkylation Conversion

DRAWN	CHECKED	APPROVED		PACE NO.	DRAWING NO.	REV.
KDS	JHJ		THE PACE CONSULTANTS HOUSTON, TEXAS	61-Y910-00	002	

FIGURE 4
USGC VALUES FOR ALKYLATE FROM DEHYDRO PLANTS

DELTA VERSUS PREMIUM GASOLINE

REQUIRED FOR 25% BTROI ON NEW ALKY INVESTMENT

REQUIRED FOR CASH COST BREAK EVEN

ACTUAL BLEND VALUE PERFORMANCE (OCTANE & RVP)

CENTS PER GALLON
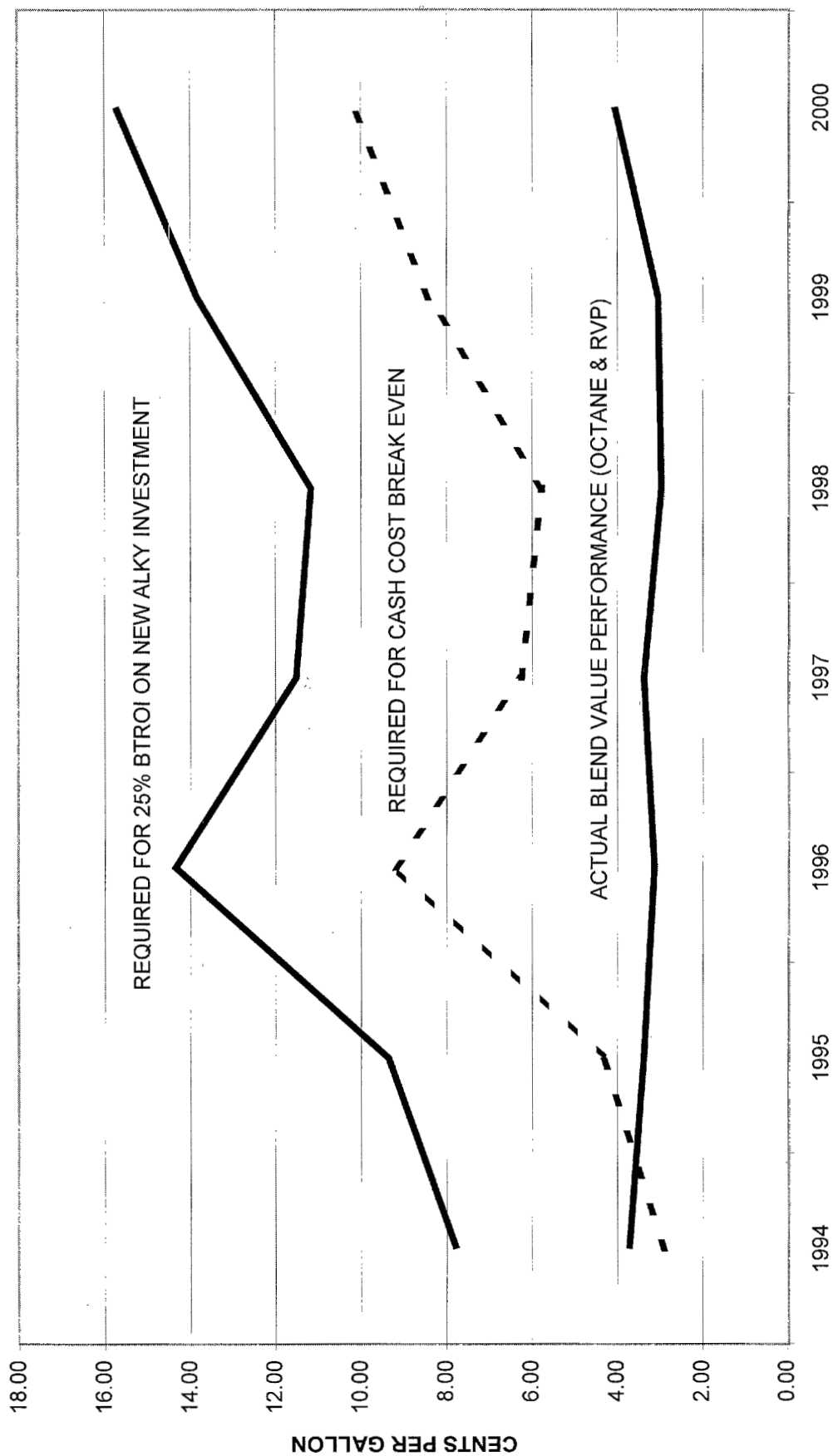
FIGURE 5
USGC PREMIUM-REGULAR GASOLINE PRICE SPREADS

TO ATTRACT ALKYLATE FROM DEHYDRO PLANTS

REQUIRED FOR 25% BTROI ON NEW ALKY INVESTMENT

REQUIRED FOR CASH COST BREAK EVEN

ACTUAL PRICE SPREADS

CENTS PER GALLON

14

12

10

8

6

4

2

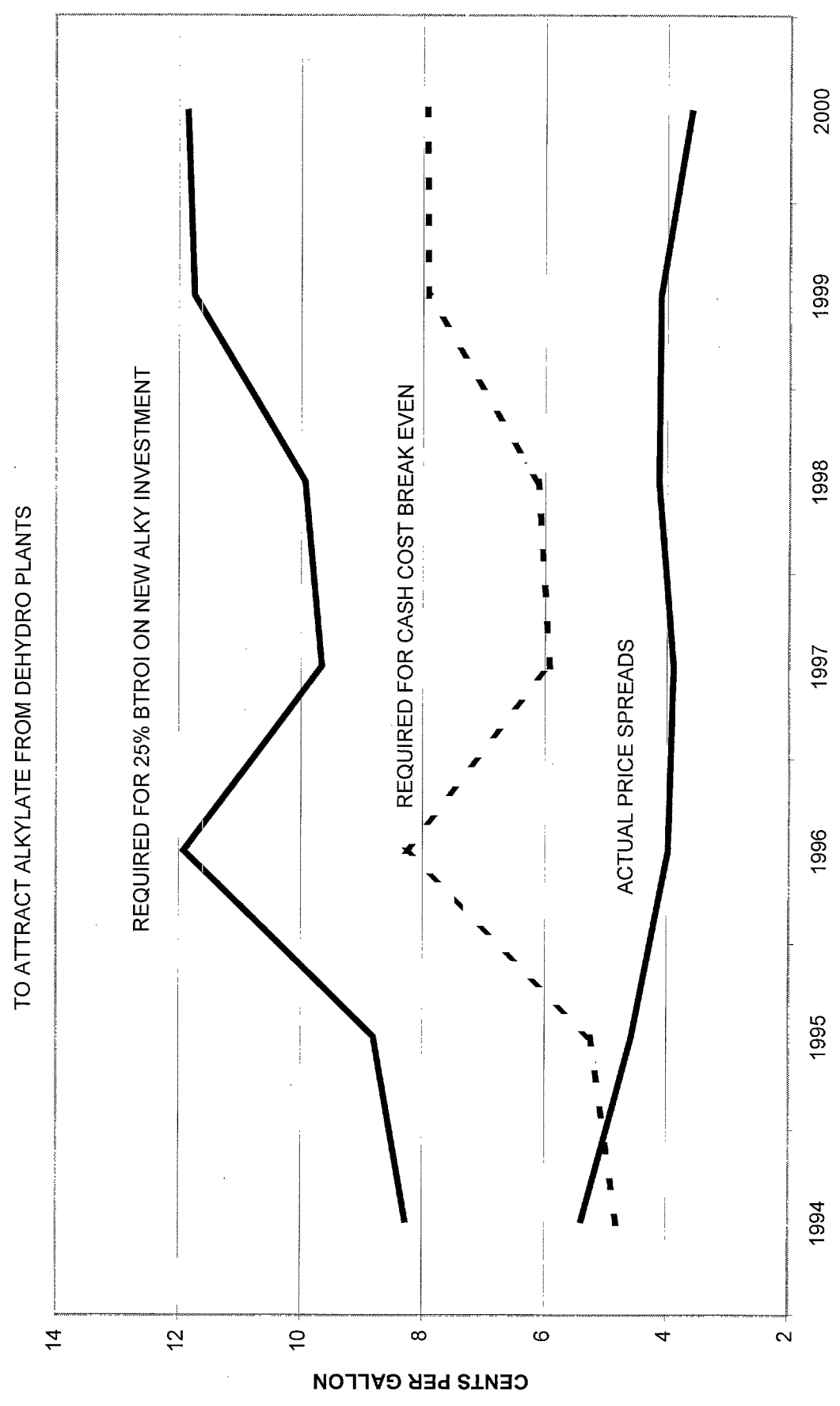1994   1995   1996   1997   1998   1999   2000

FIGURE 6

USGC VALUES FOR ISOOCTANE FROM DEHYDRO PLANTS

DELTA VERSUS PREMIUM GASOLINE